Off the Shelf, Onto the Beach

Commercial GPS in Amphibious Combat Vehicles

Seeking to take advantage of advances in GPS technology, naval researchers compared traditional waypoint navigation using a standard military GPS receiver and a moving map display with a commercial differential GPS receiver. Field trials showed that the moving map system produced better accuracy and reduced times in navigating test courses.

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Operation of amphibious assault vehicles (AAVs) in combat operations is one of the most arduous land navigation challenges faced by military forces. The U.S. Marine Corps' landing craft currently lacks an integrated navigational system. Consequently, AAV drivers have only a small viewing portal, with a dangerous blind spot, through which to see where they are going and the terrain, personnel, obstacles, and perils surrounding them. Their ability to attend to outside visual cues, such as marker buoys, may be seriously diminished by physical barriers such as sea spray, darkness, fog, and other factors.

Landing craft crew workload can be intense: the driver has numerous electronic devices to monitor, up to 18 infantry Marines to transport, and a relatively narrow lane in which to safely navigate and outside of which may be land mines. Thus, any new systems to be introduced must be very easy to interpret and understand.

Although equipped with radio capabilities, weather conditions do not always allow a crew member to give directions to the driver because of limited or nonexistent line of sight. In the near future, the Marine Corps plans to implement the Data Automated Communications System (DACT) in the AAV platform which would provide some electronic charting capability. However, not all vehicles are scheduled to receive this system. A digital navigation tool, such as a moving map, could aid an AAV driver in controlling the vehicle by displaying the vehicle's current location and track, along

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with upcoming waypoints and lane boundaries (for example, if the craft tends to drift left, then try to stay to the right side of the lane).

The Office of Naval Research (ONR) funded the Naval Research Laboratory (NRL) Moving-Map Capabilities (MMC) team (Code 7440.1) Stennis Space Center in Mississippi to equip AAVs with differential GPS (DGPS) moving map systems to test for improvements in lane navigation. NRL planned to accomplish the following tasks:

- Determine what navigation information should be displayed;
- Combine this information with precise lane coordinates;
- Display the lane as an overlay on an electronic chart;
- Evaluate how AAV drivers respond to these displays.

To develop the most reliable and accurate demonstration product possible with the funding available, NRL decided to use commercial off-the shelf (COTS) GPS products. In addition, NRL has developed software to compress different map types and imagery into the Raster Product Format Military Standard (RPF, MIL-STD-2411) to allow bathymetry data, nautical charts, and satellite and acoustic imagery to be loaded on devices that display standard National Imagery and Mapping Agency (NIMA) (recently renamed National Geospatial-Intelligence Agency or NGA) RPF data. The RPF map can display mission specific overlays, such as threat rings, lane markings, possible mine-like objects, and waypoints, to provide enhanced situational awareness. This article describes the results of the DGPS moving map development program and results from associated field trials.

Background

Military GPS receivers have changed profoundly during the past decade, benefiting from the general trend in electronics that produce smaller, lighter, lower-power, and less expensive equipment. A case study performed by the Office of the Defense Standardization Program in 1996 indicated that the AN/PSN-8 Manpack (an Army-developed 17-pound GPS receiver) cost more than $40,000. A smaller, more recent version is the Small Lightweight GPS Receiver (SLGR). During the Manpack's development, commercial GPS receivers became available. The commercial version of SLGR most attractive to the military weighed about four pounds and cost only about $4,000 each. Meanwhile, reasonably priced commercial GPS systems appeared on the market and can now be found virtually anywhere in the United States.

Amphibious Assault Vehicles (AAVs)

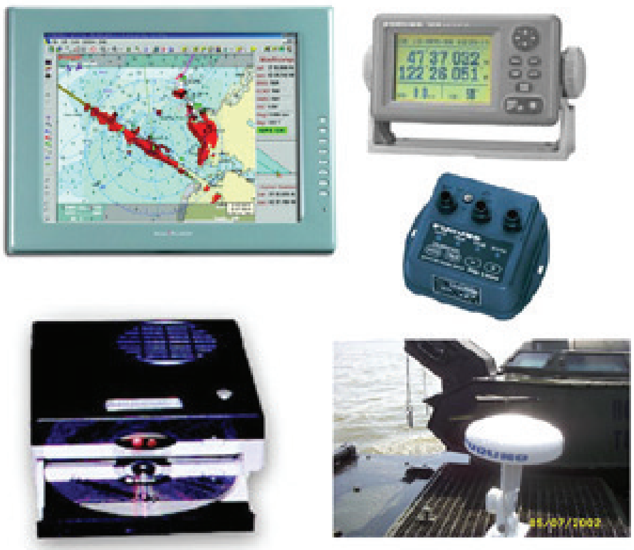
With the May 2000 discontinuance of Selective Availability (SA) based on a March 1996 Presidential Decision Directive, commercial GPS users now have access to a highly accurate, stable system of satellite signals without limitation or degradation by the GPS system operators. This ensures reliability that, until recently, was available only for military use. Consequently, the federal government now can leverage the advances made by commercial producers. Many of the nation's military platforms, including fighter jets, tanks and AAVs, were not designed to support a GPS system. Integration of a commercial GPS product on these platforms may be more appropriate than a military GPS.


The PLGR

System Components

NRL configured several AAVs with a moving map display connected to a small, portable computer temporarily installed in the rear of the vehicle. The computer is a standard 1.3 GHz PC running Windows 2000that accommodates the AAV's space restrictions. NRL configured the computer to run FalconView, which is the moving map component of the government-owned Portable Flight Planning Software (PFPS). FalconView accepts location input from any National Marine Electronics Association (NMEA) compliant GPS system, Precision Lightweight GPS Receiver (PLGR) data, and Predator unmanned airborne vehicle data. FalconView can display several different map data types, including RPF, standard NIMA charts, and standard National Oceanic and Atmospheric Administration (NOAA) charts.

The display screen was a water-resistant 10.4-inch PC color monitor, which attached to the vehicle dri-



▲ **FIGURE 1 System Components.** Clockwise from top left: Portable computer display screen, DGPS receiver, heading sensor, DGPS antenna, and computer.

ver's hatch as is visible in **Figure 2** to be out of the way when the vehicle was not in operation.

A DGPS antenna was placed on the outside of the vehicle, slightly aft of the crew chief hatch. The antenna was connected to a DGPS receiver using a preexisting thru-hull cavity. A heading sensor was used to stabilize the view on the moving map display while the vehicle was stationary. Without independent heading inputs from the magnetic heading sensor, the map display will spin, cause by erratic heading information from the DGPS receiver when the vehicle is stopped or moving slower than one nautical mile per hour. NRL wrote software to integrate the heading sensor data with the DGPS data for input into FalconView. The system components are shown in **Figure 1**.

Testing

NRL's moving map has been tested on the AAV platform three times during the past 18 months: on both the Navy's Landing Craft Utility (LCU) and Landing Craft Air Cushion (LCAC) in addition to the AAV. Testing on the LCAC platform was not nearly as extensive as the other platforms, due to the operational cost of the craft. Therefore, any data collected from that demonstration could not be considered statistically significant. LCU testing was as extensive as the testing on the AAV platform, with similar results.

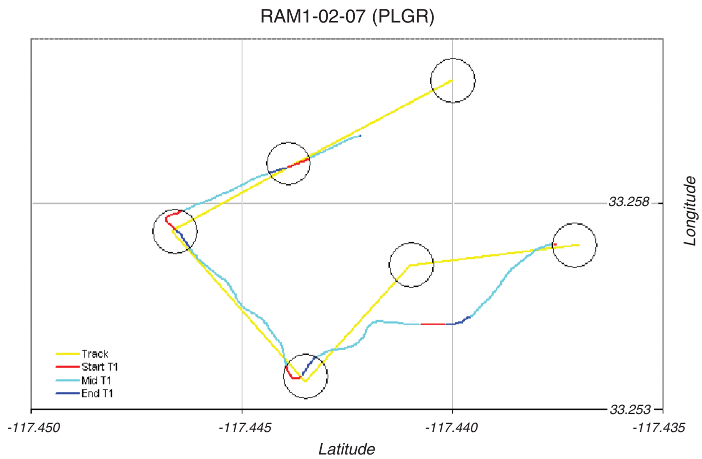
The primary difference between platforms, as far as the moving map testing was concerned, was NRL's ability to use the available gyrocompass on the LCU in order to obtain reliable heading. A magnetic heading sensor was not feasible on the LCU platform because the craft is mostly constructed using ferrous materials, as opposed to the AAV's aluminum hull. The article focuses on the AAV testing and results.

AAV testing took place at the Amphibious Vehicle Test Branch (AVTB) at Camp Pendleton, California, and at the 3rd Platoon, Company A, 4th Assault Amphibian Battalion Reserve Unit at the CB Base in Gulfport, Mississippi. After arriving on site, the NRL team spent one day installing the moving map equipment on the test vehicles and conducting a short training session for the crew. The following days were spent testing the system and evaluating crew performance navigating with the moving map versus using their baseline means of navigation.

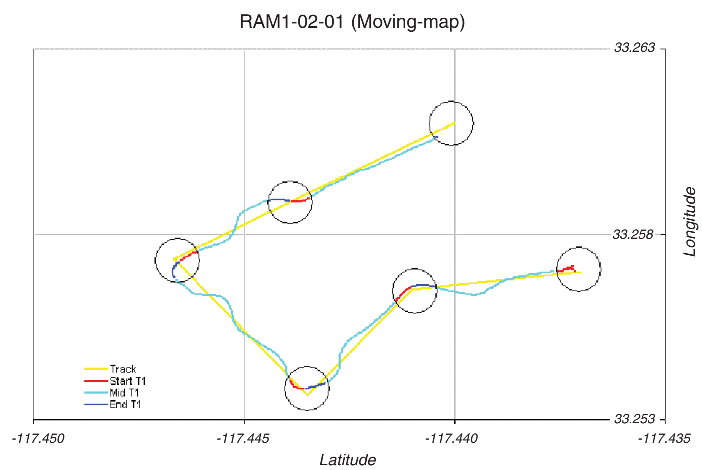
The baseline – and only – means of navigation available to the AAV crew at this time is a military PLGR. The PLGR displays the vehicle position in latitude and longitude on a small handheld device and provides navigation guidance by indicating whether to turn left or right – based on the preset course – to reach the next waypoint. Standard procedure calls for the crew chief to operate the PLGR while relaying directional information and instructions to the driver. All driver/crew chief communication takes place through an internal radio link, as the crew chief is located on the opposite side of the vehicle, as shown in Figure 2.

Although the PLGR was used as the baseline for testing, it is not always available to every AAV crew in either training or wartime environments. Moreover, the crew members in the NRL trials exhibited unfamiliarity with its function, which required additional time to train them in PLGR operation. After the initial PLGR training, the NRL team spent about ten minutes explaining the moving map concept and in-

▲ **FIGURE 2** Driver and crew chief positions



▲ **FIGURE 3** Example run using PLGR



▲ **FIGURE 4** Example run using moving map

structing drivers on its operation.

Each test or demonstration took place on a predetermined course based on the area in which the vehicles were cleared to operate. Specific waypoints were entered into both the moving map system and the PLGR. The PLGR showed position numerically, while the moving map system showed position graphically.

When navigating with the moving-map display, AAV drivers were instructed to follow the lane markings on the display and to stay as close to the centerline as possible. When navigating with the PLGR, AAV drivers were told to aim for the next waypoint as precisely as possible. The moving-map display was turned off during PLGR tests, and PLGR were not issued to drivers during moving map tests. Both test conditions (moving map and PLGR) were repeated with the same drivers on the same course, in both clockwise and counterclockwise directions to reduce familiarity. These runs were repeated over several days, with vehicle positions recorded once per second by the NRL moving map system's computer for later analysis.

Results

Test results calculated how well the drivers could stay in their lanes using the moving map compared to results when using the PLGR. This was accomplished by comparing each individual run to the actual course measured in terms of cross track error (CTE), which is the positive perpendicular distance between the planned route and the actual track (recorded as a series of latitude and longitude points from the DGPS receiver), and is similar in magnitude to root mean square error:

$$\mathbf{CTE_P} = \frac{|\, C_X C_Y * [(Y_E - Y_S)(X_P - X_S) - (X_E - X_S)(Y_P - Y_S)]\,|}{\mathrm{SQRT}\,[\,(C_X\,(X_E - X_S))^2 + (C_Y\,(Y_E - Y_S))^2]}$$

Where:

C_X = constant to convert longitude into meters (for the average latitude of the course),

C_Y = constant to convert latitude into meters (which is independent of longitude),

(X_P, Y_P) = longitude (X) and latitude (Y) of the DGPS point along the actual track,

(X_S, Y_S) = longitude and latitude of the starting point of the planned route segment, and

(X_E, Y_E) = longitude and latitude of the ending point of the planned route segment.

The CTE for the entire track is calculated as the average of the individual CTEs for all points recorded along the track, which is broken into turns and straight sections. For better comparisons, average CTE values are calculated separately for each type of section.

The drivers who had experience using a PLGR were reluctant to accept that the moving-map display might improve their lane navigation performance. However, even the experienced driver of the track shown in **Figure 3** experienced a common PLGR problem: missing a waypoint. When a waypoint is accidentally missed while using a PLGR, the driver can only aim for the next waypoint. Using PLGR navigation, a driver has no way to regain the track until the AAV reaches the next waypoint. This creates a potentially dangerous situation, because the AAV runs the risk of hitting a mine whenever it is outside the predetermined lane. The longer it remains outside the lane, the more risk it faces.

Both tracks in **Figures 3** and **4** show small back-and-forth movements around the centerline. Discussions with the crew revealed that this is a necessary maneuver to cut through waves. If the AAV moves straight forward, its hull would be buried beneath the surface and slow down considerably. Instead, the driver tends to weave back and forth across the surface.

The plots in **Figure 5** reveal significant reductions

in CTE (and, thus, a significant reduction in lane width requirements) when driving with the moving-map display compared to PLGR-aided navigation. Table 1 shows the numerical values of these results. Such a reduction in lane width equates to a corresponding reduction in labor, time, and threat to safety required to clear the lane prior to an assault. On average, drivers were able to complete the course in significantly less time with the moving-map (~11 minutes) compared to the PLGR (~14 minutes), which would further reduce crew exposure to potential risks during an assault.

Conclusions

The Naval Research Laboratory investigated, developed, and demonstrated COTS moving map software on COTS hardware (including commercial GPS) to graphically display precise lane navigation. The demonstrated system provides an improved means of guiding AAV drivers through a cleared lane to the beach during an amphibious assault in the presence of mines. During these tests and military demonstrations, we concluded that the use of commercial GPS equipment is a very cost-effective and reliable option for military amphibious assault missions.

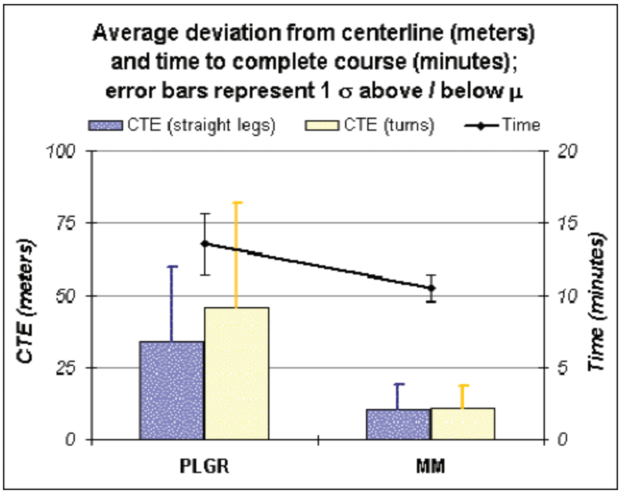
AAV crew members reported that the moving-map system demonstrated to them was easy to operate with minimal training and very effective in helping operators keep the vehicle within the lane. As one operator put it, "This is a step in the right direction!"

The moving map system demonstrated by NRL significantly improved the navigation performance of AAV platform by enhancing crew situational awareness, improving crew communications, and decreasing crew reaction times, compared with existing systems. Based on these results, the Mine Warfare Readiness and Effectiveness Measuring (MIREM) team recently recommended in a fleet-wide Navy message that "some type of graphic navigation system/display should be expedited to the fleet. The system should provide . . . clear navigational and situational awareness (craft displayed relative to intended track), direct interface with the craft driver (reduced maneuvering reaction time), and a means to ingest and display EDSS data (minimized error in entry and transfer of information)."

We must emphasize that the commercial products used in these demonstrations were not military standard compliant; therefore, a more robust system would need to be employed for wartime events. This would include fully ruggedized hardware and GPS receivers with the capability to receive and translate military signals, such as P/Y and M codes.

TABLE 1 Cross Track Error (CTE) in Field Tests (in meters)

Course Section	PLGR	MM
Straight Legs	32.78	10.77
Turns	41.85	10.88



▲ **FIGURE 5** Summary of AAV test runs during the Transparent Hunter 2003 (TH03) military exercise, using precision lightweight GPS receiver (PGLR) and moving map MM.

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Manufacturers

The *Precision Lightweight GPS Receiver* (PLGR) is produced by **Rockwell Collins** (Cedar Rapids, Iowa). The moving map system used a *GP-36* differential GPS receiver and DGPS antenna and *PG-1000* magnetic heading sensor, both from **Furuno USA Inc.** (Camas, Washington), running on a Windows 2000-based *Marinus MPC* personal computer by **Argonaut Computer, Inc.** (La Jolla, California), and displayed on a 10.4-inch *Sunlight Infinity Series* display by **Nauticomp Inc.** (Lindsay, Ontario).